General Engineering Principles I

General Engineering Principles I

Forces:

Tensile and Compressive:

- Tensile (Tension) - pulling apart
- Compressive (Compression) - pushing together
- Forces may be direct, or may be caused by changes in pressure, temperature, or combined loads.

Shear:

- Force perpendicular to the primary axis.

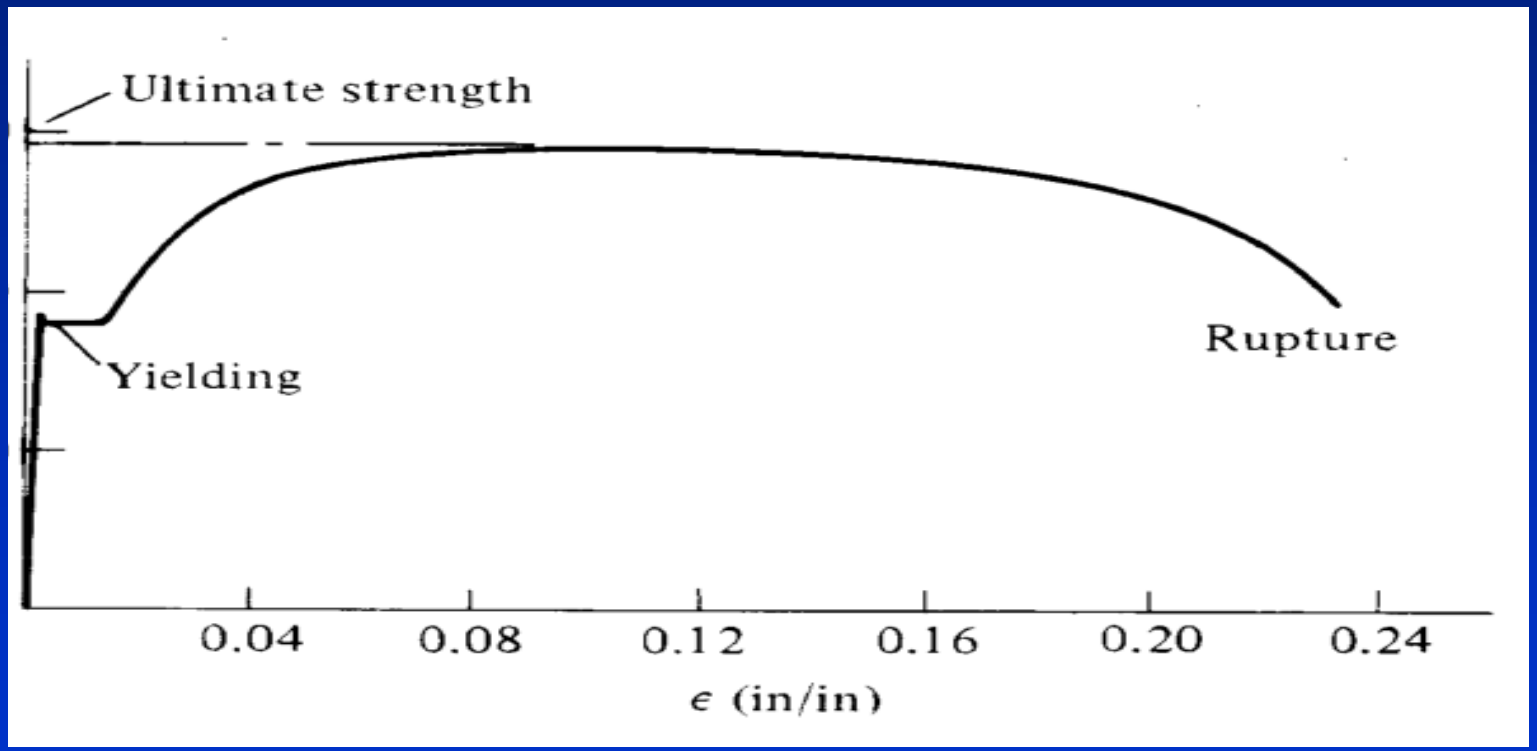
General Engineering Principles I

Strength:

- Stress = Force/Area (psi or Pa)
- Strain = Elongation under stress =change in length/original length (in./in.)
- Ultimate Strength: maximum stress sustained without breaking - exceed this limit and the material will break.
- Yield Strength: maximum stress sustained without permanent deformation - the material will stretch and come back to its original length.

General Engineering Principles I

Stress vs. Strain:



General Engineering Principles I

Strength (cont.):

Basic Properties of Several Metals

Material	Density,† g/cm³	Coefficient of thermal expansion, in/(in)(°F) × 10^{-6}	Thermal conductivity, Btu/(h)(ft)(°F)	Specific heat, Btu/(lb)(°F)	Approx melting temp, °F	Modulus of elasticity lb/in² × 10^6	Poisson's ratio	Yield stress, lb/in² × 10^3	Ultimate stress, lb/in² × 10^3	Elongation, %
Aluminum, 2024-T3	2.77	12.6	110	0.23	940	10.6	0.33	50	70	18
Aluminum, 6061-T6	2.70	13.5	90	0.23	1080	10.6	0.33	40	45	17
Aluminum, 7079-T6	2.74	13.7	70	0.23	900	10.4	0.33	68	78	14
Beryllium, QMV	1.85	6.4–10.2	85	0.45	2340	40–44	0.024–0.030	27–38	33–51	1–3.5
Copper, pure	8.90	9.2	227	0.092	1980	17.0		See "Metals Handbook"		
Gold, pure	19.32		172	0.031	1950	10.8	0.42		18	30
Lead, pure	11.34	29.3	21.4	0.031	620	2.0	0.40–0.45	1.3	2.6	20–50
Magnesium AZ31B-H24 (sheet)	1.77	14.5	55	0.25	1100	6.5	0.35	22	37	15
Magnesium, HK31A-H24	1.79	14.0	66	0.13	1100	6.4	0.35	29	37	8
Molybdenum, wrought	10.3	3.0	83	0.07	4730	40.0	0.32	80	120–200	Small
Nickel, pure	8.9	7.2	53	0.11	2650	32.0		See "Metals Handbook"		
Platinum	21.45	5.0	40	0.031	3217	21.3	0.39		20–24	35–40
Plutonium, alpha phase	19.0–19.7	30.0	4.8	0.034	1184	14.0	0.15–0.21	40	60	Small
Silver, pure	10.5	11.0	241	0.056	1760	10–11	0.37	8	18	48
Steel, AISI C1020 (hot-worked)	7.85	6.3	27	0.10	2750	29–30	0.29	48	65	36
Steel, AISI 304 (sheet)	8.03	9.9	9.4	0.12	2600	28	0.29	39	87	65
Tantalum	16.6	3.6	31	0.03	5425	27.0	0.35		50–145	1–40
Thorium, induction melt	11.6	6.95	21.7	0.03	3200	7–10	0.27	21	32	34
Titanium, B 120VCA (aged)	4.85	5.2	4.3	0.13	3100	14.8	0.3	190	200	9
Tungsten	19.3	2.5	95	0.033	6200	50	0.28		18–600	1–3
Uranium D-38	18.97	4.0–8.0	17	0.028	2100	24	0.21	28	56	4

General Engineering Principles I

Strength (cont.):

Table 6.4.1 Physical Constants of the Principal Alloy-Forming Elements

	Atomic No.	Atomic weight	Density, lb/in³	Melting point, °F	Boiling point, °F	Specific heat†	Latent heat of fusion, Btu/lb	Linear coef of thermal exp. per °F × 10⁻⁶	Thermal conductivity (near 68°F), Btu/(ft²)(h)(in)(°F)	Electrical resistivity, μΩ·cm	Modulus of elasticity (tension), lb/in² × 10⁶	Crystal structure‡	Transition temp. °F	Symbol
Aluminum	13	26.97	0.09751	1220.4	4520	0.215	170	13.3	1,540	2.655	10	FCC		Al
Antimony	51	121.76	0.239	1166.9	2620	0.049	68.9	4.7–7.0	131	39.0	11.3	Rhom		Sb
Arsenic	33	74.91	0.207	1497	1130	0.082	159	2.6		35	11	Rhom		As
Barium	56	137.36	0.13	1300	2980	0.068		(10)		50	1.8	BCC		Ba
Beryllium	4	9.02	0.0658	2340	5020	0.52	470	6.9	1,100	5.9	37	HCP		Be
Bismuth	83	209.00	0.354	520.3	2590	0.029	22.5	7.4	58	106.8	4.6	Rhom		Bi
Boron	5	10.82	0.083	3812	4620	0.309		4.6		1.8×10^{12}		O		B
Cadmium	48	112.41	0.313	609.6	1409	0.055	23.8	16.6	639	6.83	8	HCP		Cd
Calcium	20	40.08	0.056	1560	2625	0.149	100	12	871	3.43	3	FCC/BCC	867	Ca
Carbon	6	12.010	0.0802	6700	8730	0.165		0.3–2.4	165	1,375	0.7	Hex/D		C
Cerium	58	140.13	0.25	1460	4380	0.042	27.2			78		HCP/FCC	572/1328	Ce
Chromium	24	52.01	0.260	3350	4500	0.11	146	3.4	464	13	36	BCC/FCC	3344	Cr
Cobalt	27	58.94	0.32	2723	6420	0.099	112	6.8	479	6.24	30	HCP/FCC/HCP	783/2048	Co
Columbium (niobium)	41	92.91	0.310	4380	5970	0.065		4.0		13.1	15	BCC		Cb
Copper	29	63.54	0.324	1981.4	4700	0.092	91.1	9.2	2,730	1.673	16	FCC		Cu
Gadolinium	64	156.9	0.287									HCP		Gd
Gallium	31	69.72	0.216	85.5	3600	0.0977	34.5	10.1	232	56.8	1	O		Ga
Germanium	32	72.60	0.192	1756	4890	0.086	205.7	(3.3)		60×10^{6}	11.4	D		Ge
Gold	79	197.2	0.698	1945.4	5380	0.031	29.0	7.9	2,060	2.19	12	FCC		Au
Hafnium	72	178.6	0.473	3865	9700	0.0351		(3.3)		32.4	20	HCP/BCC	3540	Hf
Hydrogen	1	1.0080	3.026×10^{-6}	-434.6	−422.9	3.45	27.0		1.18			Hex		H
Indium	49	114.76	0.264	313.5	3630	0.057	12.2	18	175	8.37	1.57	FCT		In
Iridium	77	193.1	0.813	4449	9600	0.031	47	3.8	406	5.3	75	FCC		Ir
Iron	26	55.85	0.284	2802	4960	0.108	117	6.50	523	9.71	28.5	BCC/FCC/BCC	1663/2554	Fe
Lanthanum	57	138.92	0.223	1535	8000	0.0448				59	5	HCP/FCC/?	662/1427	La
Lead	82	207.21	0.4097	621.3	3160	0.031	11.3	16.3	241	20.65	2.6	FCC		Pb
Lithium	3	6.940	0.019	367	2500	0.79	286	31	494	11.7	1.7	BCC		Li
Magnesium	12	24.32	0.0628	1202	2030	0.25	160	14	1,100	4.46	6.5	HCP		Mg
Manganese	25	54.93	0.268	2273	3900	0.115	115	12		185	23	CCX/CCX/FCT	1340/2010/2080	Mn

General Engineering Principles I

Strength (cont.):

Mercury	80	200.61	0.4896	−37.97	675	0.033	4.9	33.8	58	94.1		Rhom		Hg
Molybdenum	42	95.95	0.369	4750	8670	0.061	126	3.0	1,020	5.17	50	BCC		Mo
Nickel	28	58.69	0.322	2651	4950	0.105	133	7.4	639	6.84	30	FCC		Ni
Niobium (see Columbium)														Nb
Nitrogen	7	14.008	0.042×10^{-3}	−346	−320.4	0.247	11.2		0.147			Hex		N
Osmium	76	190.2	0.813	4900	9900	0.031		2.6		9.5	80	HCP		Os
Oxygen	8	16.000	0.048×10^{-3}	−361.8	−297.4	0.218	5.9		0.171			C		O
Palladium	46	106.7	0.434	2829	7200	0.058	69.5	6.6	494	10.8	17	FCC		Pd
Phosphorus	15	30.98	0.0658	111.4	536	0.177	9.0	70		10^{17}		C		P
Platinum	78	195.23	0.7750	3224.3	7970	0.032	49	4.9	494	9.83	21	FCC		Pt
Plutonium	94	239	0.686	1229				50–65		150		MC	6 forms	Pu
Potassium	19	39.096	0.031	145	1420	0.177	26.1	46	697	6.15	0.5	BCC		K
Radium	88	226.05	0.18	1300								?		Ra
Rhenium	75	186.31	0.765	5733	10,700	0.0326	76			21	75	HCP		Re
Rhodium	45	102.91	0.4495	3571	8100	0.059		4.6	610	4.5	54	FCC		Rh
Selenium	34	78.96	0.174	428	1260	0.084	29.6	21	3	12	8.4	MC/Hex	248	Se
Silicon	14	28.06	0.084	2605	4200	0.162	607	1.6–4.1	581	10^{5}	16	D		Si
Silver	47	107.88	0.379	1760.9	4010	0.056	45.0	10.9	2,900	1.59	11	FCC		Ag
Sodium	11	22.997	0.035	207.9	1638	0.295	49.5	39	929	4.2	1.3	BCC		Na
Sulfur	16	32.066	0.0748	246.2	832.3	0.175	16.7	36	1.83	2×10^{23}		Rhom/FCC	204	S
Tantalum	73	180.88	0.600	5420	9570	0.036		3.6	377	12.4	27	BCC		Ta
Tellurium	52	127.61	0.225	840	2530	0.047	13.1	9.3	41	2×10^{5}	6	Hex		Te
Thallium	81	204.39	0.428	577	2655	0.031	9.1	16.6	2,700	18	1.2	HCP/BCC	446	Tl
Thorium	90	232.12	0.422	3348	8100	0.0355	35.6	6.2		18.6	11.4	FCC		Th
Tin	50	118.70	0.264	449.4	4120	0.054	26.1	13	464	11.5	6	D/BCT	55	Sn
Titanium	22	47.90	0.164	3074	6395	0.139	187	4.7	119	47.8	16.8	HCP/BCC	1650	Ti
Tungsten	74	183.92	0.697	6150	10,700	0.032	79	2.4	900	5.5	50	BCC		W
Uranium	92	238.07	0.687	2065	7100	0.028	19.8	11.4	186	29	29.7	O/Tet/BCC	1229/1427	U
Vanadium	23	50.95	0.217	3452	5430	0.120		4.3	215	26	18.4	BCC	2822	V
Zinc	30	65.38	0.258	787	1663	0.092	43.3	9.4–22	784	5.92	12	HCP		Zn
Zirconium	40	91.22	0.23	3326	9030	0.066		3.1	116	41.0	11	HCP/BCC	1585	Zr

General Engineering Principles I

Ductility:

- A metal is ductile when it can be drawn out in tension without rupture (Opposite of Brittle metals).
- A ductile metal must be strong and plastic.
- Ductile materials have large difference between yield and ultimate strengths.
- Lead wire is difficult to draw because the strength of lead is low.

General Engineering Principles I

Hardness:

- Resistance to local penetration, scratching, machining, wear or abrasion.
- Different measurement scales (Rockwell, Brinell, Vickers).
- Hard materials exhibit brittle, catastrophic failure. Therefore, for very hard materials, there is no indication of whether the component is close to failure.

General Engineering Principles I

Brittleness:

- Is the property of breaking without much permanent distortion
- It may be due to brittleness of the grain boundaries or of the crystal themselves. Excessive presence of sulfur in steel makes it brittle in elevated temperatures.
- When the phosphorus contents are too high in steels, they exhibit brittleness at cold temperatures.

General Engineering Principles I

Elasticity:

- The elasticity of a metal is its power of returning to its original shape after deformation by a force. Many materials behave to some extent like powerful elastics, and, within limits, will recover their shape when load on them is removed.

- For example, if the elastic limit of a material were 15 tons per square inch, then with bar of material 1 Sq. in. in area, the material would return to its original length from a load of 15 tons. If this loading was exceeded, the material would permanently stretch.

General Engineering Principles I

Elongation:

- When a material is pulled in a testing machine for the purpose of finding its tensile strength, stretch takes place before the bar breaks. The elongation is the amount of this stretch and is generally expressed as a percentage.

- If a metal length of 2 in. stretched to 2 3/4 in, before fracturing, the elongation would be, {(2 3/4 in. - 2 in.)/2} x 100 = 37 ½ per cent.

- A good elongation indicates a ductile material.

General Engineering Principles I

Malleability:

- This is a property of permanently extending in all directions without rupture by pressing, hammering, rolling etc.
- It requires that the metal will be plastic but is not dependent on strength, e.g., lead is a very malleable metal.

General Engineering Principles I

Plasticity:

- This is rather similar to malleability, and involves permanent deformation without rupture. It is the extreme opposite of elasticity.

- Plasticity is necessary for forging, i.e., steel is plastic when at bright red heat.

General Engineering Principles I

Toughness:

- Is the amount of energy a material can absorb before fracture
- A measure of the toughness of a metal may be obtained by nicking it, placing it in a vise and striking the end with a hammer.
- Certain woods are very tough. It is for this reason that hickory is a good material for sledge-shafts.

General Engineering Principles I

Melting Points:

- Very important when discussing fires. Lead will usually melt in a fire.
- Important for seals and gaskets in high temperatures. The seals and gaskets will be rendered useless.
- Adhesives usually won't survive well in high temperatures.

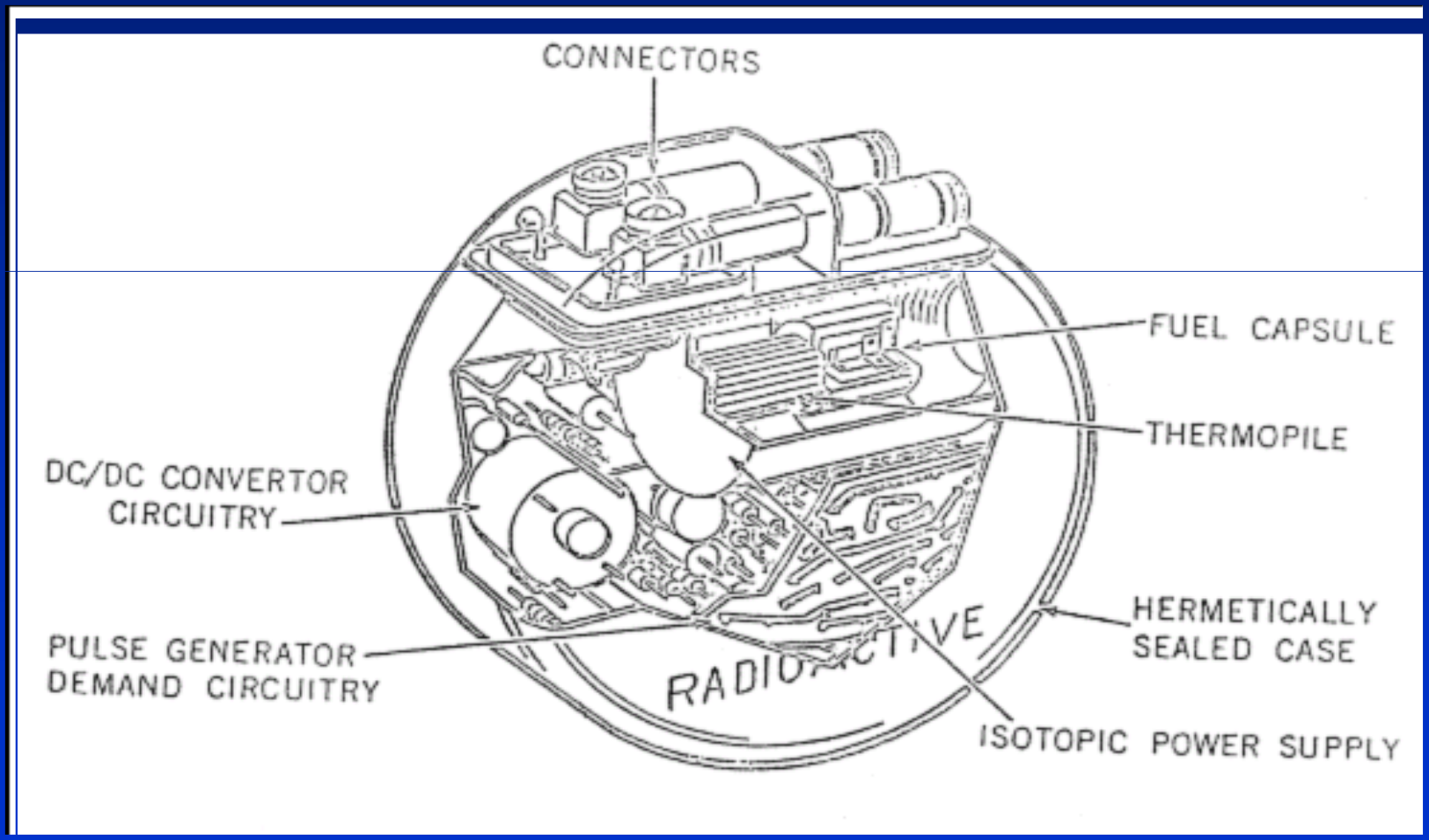
General Engineering Principles I

Thermal Expansion:

- Materials expand as temperature increases and contract when temperature decreases.
- No void spaces, such as in source capsules, could cause tension and possible rupture.
- Thermal cycling causes tension and compression therefore the possibility of fatigue failure. Could be caused by internal pressures (such as in sources) or in a member itself (concrete joints).

General Engineering Principles I

Thermal Expansion: (Cont.)



General Engineering Principles I

Moments:

- Compressive forces at one edge and tensile forces at the other edge.
- Usually of concern when loads are applied perpendicular to the primary axis of a rod or plate.
- Standard formulas for calculating moments.
- Example: Irradiator sources require a bend tests.

General Engineering Principles I

Torsion/Torque:

- Twisting of a component around it primary axis.
- Usually applies for turning a shaft, such as a shutter.
- The larger the lever arm, the greater the torque.
- A large weight that rotates at a large distance from the center of a shaft will create a large torque.

General Engineering Principles I

Slenderness:

- The ability of the component to bend (sometimes referred to as buckling).
- Different than moments in that it is created by a load being applied along the primary axis.
- Length to Diameter ratio is usually very important. The higher the ratio, the more likely it is to bend.

General Engineering Principles I

Poisson's Ratio:

- If a bar is subjected to a longitudinal stress there will be a strain in this direction equal to E/Stress. There will also be a strain in all directions at right angles to the longitudinal stress. It is found that for elastic metals the lateral strain is proportional to the longitudinal strain, and is of the opposite type.

- The ratio Lateral strain / Longitudinal strain is called Poisson's Ratio.

General Engineering Principles I

Normalizing:

- The object of normalizing is to refine the structure of steel and remove strains which may have been caused by cold working. This process is necessary when steel is kept at higher temperatures for prolonged periods during forging or cold working.

- If the steel is slowly heated to its annealing temperature, the structure is in the most refined state, and normalizing consists of cooling in the air.

General Engineering Principles I

Annealing:

- The purpose of the annealing is so that steel can be more easily machined. To relieve internal stresses which may have been caused by the cold work or by unequal contractions in a casting.

- The process involves heating slowly, and holding at a temperature long enough to enable internal changes to take place and than cooling slowly. Annealing temperature is lower with increasing carbon contents.

General Engineering Principles I

Shape of Components:

- Beams - round, rectangular, solid or hollow

- Plate - is a rolled product more than 3.0 mm thick, supplied flat as in the case of a sheet. It may be hot rolled only, but in a thinner gauge it can also be offered cold-rolled, when it will have better finish and closer tolerance than hot-rolled equivalent.

General Engineering Principles I

Shapes of Components: (Cont.)

- Sheets and strips - are cold rolled products with thickness greater than 0.2 mm but not exceeding 3.0 mm. A sheet is supplied flat, where as strip is coil form. A sheet may, however, be manufactured as strip and cut to length.

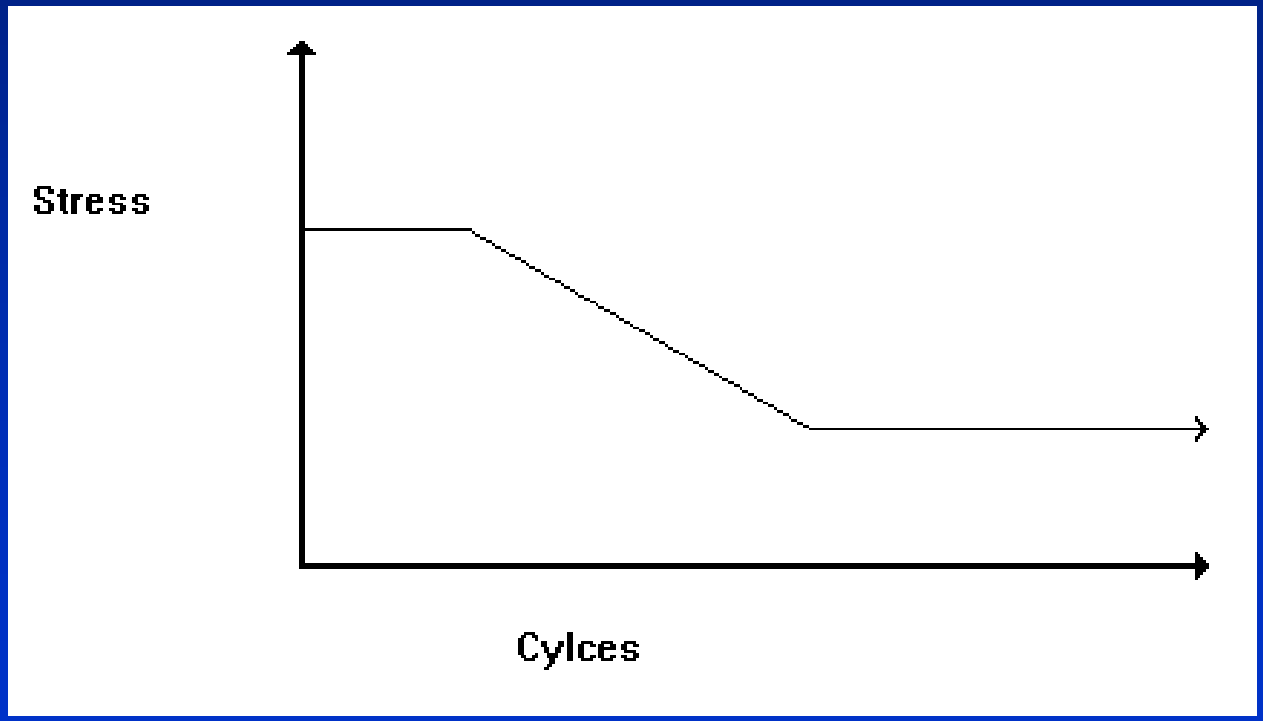
General Engineering Principles I

Fatigue:

- May be caused by thermal cycling or vibration.
- Failure from repeated loading and unloading, where the loads are below the ultimate strength of the material.
- Tensile stresses are more destructive than compressive stresses.

General Engineering Principles I

Fatigue (cont.):



General Engineering Principles I

Engineering Analysis:

- Used to evaluate design based on prototype testing of an earlier design and to verify adequacy of deviations in testing procedures or conditions.
- Used to extrapolate results to other products, for which design and testing have been approved, such as a design series or other conditions of use.
- Used to evaluate changes in the product design. These usually occur as part of an amendment request.

General Engineering Principles I

Typical Analysis:

- Finite Element Methods
- Cyclic Stress Analysis
- Heat Transfer Analysis
- Failure Analysis
- Safety Analysis

General Engineering Principles I

Environmental Effect on Metals:

Atmosphere:

- most metals react with oxygen, particularly at elevated temperature
- chemical attack
- hydrogen & nitrogen embrittlement

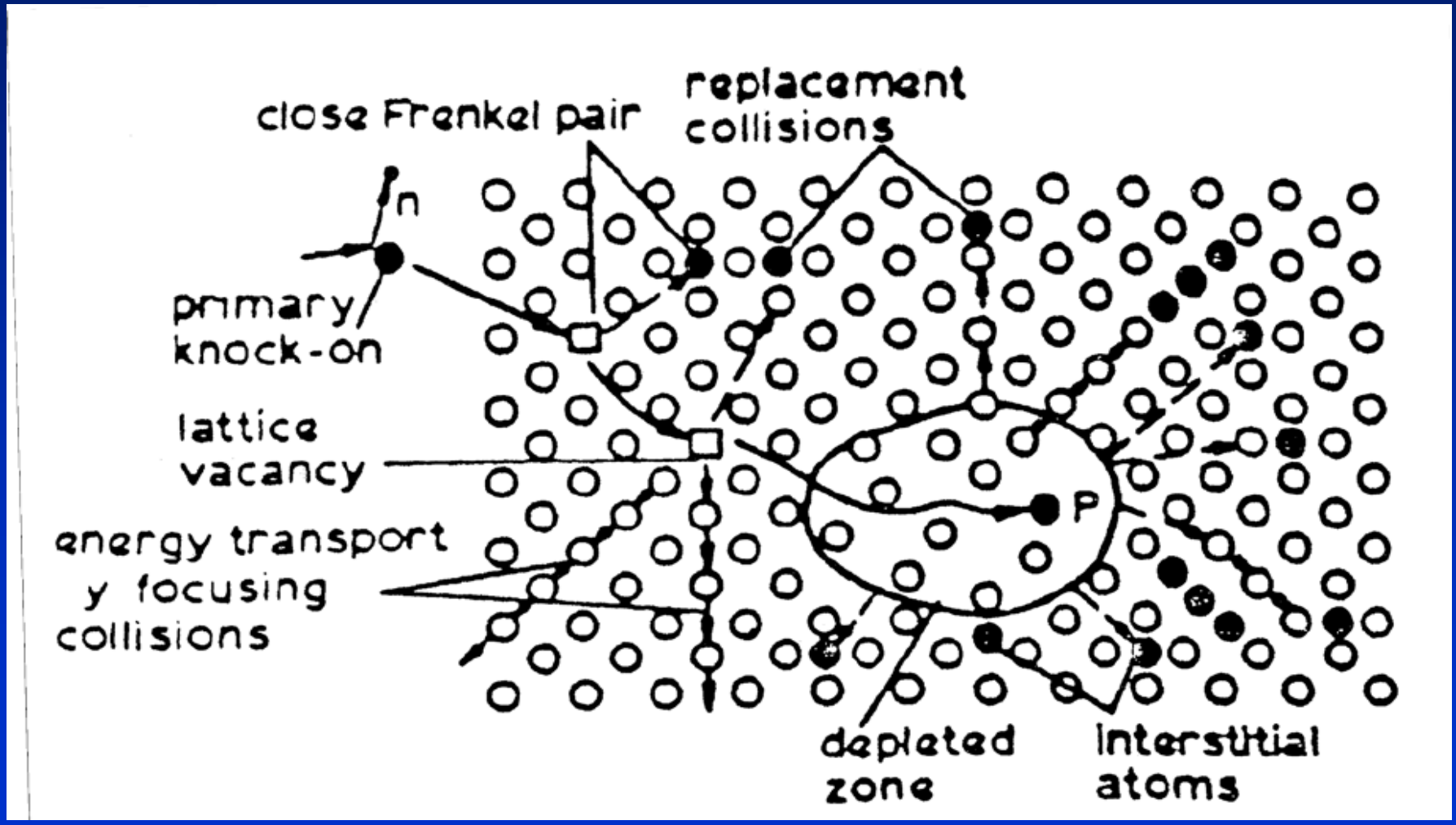
General Engineering Principles I

Environmental Effect on Metals:

Radiation:

- Can affect internal structure of all materials causing a breakdown in their properties (esp. lubricants, adhesives, gaskets, Teflon, etc.)

General Engineering Principles I



General Engineering Principles I

Environmental Effect on Metals:

Chemical:

- material dissolves or are attacked by corrosive liquids, gasses, acids or alkalies
- leaching occurs when an element is removed as a result of corrosion (i.e., dezincification of brass)

General Engineering Principles I

Environmental Effect on Metals :

Electrochemical:

- Formation of an electrochemical cell requires:

- an anode
- a cathode
- an electrolyte

General Engineering Principles I

Environment Effect on Metals:

Corrosion:

- Transfer of electrons form one species to another metal ions characteristically lose or give up electrons in an oxidation reaction

$$M \rightarrow Mn+ + ne-$$

example:

$$Fe \rightarrow Fe++ + 2e-$$

$$Al \rightarrow Al+++ + 3e-$$

- Sites at which the oxidation reaction takes place are the anodes.

General Engineering Principles I

- **Environmental Effect on Metals:**

Corrosion:

- The electrons generated from the oxidation process must be transferred become part of another reaction known as the reduction reaction.

- (acid solution) $2H^+ + 2e^- \rightarrow H_2$ (gas)

- (aerated water) $O_2 + 2H_2O + 4e^- \rightarrow 4(OH^-)$

General Engineering Principles I

Environmental Effect on Metals:

Corrosion Cont.

- Example: Oxidation/rusting of iron in water which contains dissolved oxygen

- $Fe + \frac{1}{2} O_2 + H_2O \rightarrow Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$
- $2Fe(OH)_2 + \frac{1}{2}O_2 + H_2O \rightarrow 2Fe(OH)_3$

- $Fe(OH)_3$ is an insoluble compound (rust) with non-metallic elements.

General Engineering Principles I

Corrosion (continued):

Galvanic series

Anodic End	Cathodic End
Magnesium	Inconel (Active)
Magnesium Alloys	Hastelloy C (active)
Zinc	Brasses
Galvanized Steel	Copper
Aluminum 5052	Bronzes
Aluminum 3003	Cupro-Nickel Alloys
Aluminum 6061	Monel
Cadmium	Silver Solder
Aluminum 2017	Nickel (passive)
Aluminum 2024	Inconel (passive)
Iron and Carbon Steel	Ferritic Stainless Steel (passive)
Ferritic Stainless Steel 400 series (active)	Austenitic Stainless Steel (passive)
Austenitic Stainless Steel (active) 18-8 series	Titanium
316 Stainless Steel (active)	Silver
Lead	Graphite
Tin	Gold
Nickel (active)	Platinum

General Engineering Principles I

Environmental Effect on Metals:

Corrosion:

Galvanic Corrosion

- Two metals or alloys having different compositions that are electrically coupled while exposed to an electrolyte
- Examples: Steel/brass interface, copper/steel pipe fittings

Prevention

- If coupling of dissimilar metals is necessary, choose metals that are close in the galvanic series
- Use an anode area as large as possible
- Electrically insulate the dissimilar metals

General Engineering Principles I

Comparative Alloy Performance:

ENVIRONMENT	Not Suggested	Good	Better	Best
CHLORIDES (pitting, crevice corrosion)	304L	20Cb-3® RA333® E-BRITE,® 316L, 200[a], 600	RA904L™ 400[a]	AL-6XN® Titanium
CHLORIDE STRESS CORROSION CRACKING	304L 316L		RA904L	E-BRITE, 200, 400, 600 RA333®, 20Cb-3, AL-6XN, RA330®
HYDROCHLORIC ACID	Titanium[c] 600, 20Cb-3, 2205 E-BRITE	AL-6XN[b] 200,[a] 400[a]	59 C-22 C-276	Zirconium[a] alloy B-2[a] Tantalum Titanium[c]
HYDROFLUORIC ACID	200, 600, Ta, 2205, etc.	Copper[a]	400[a] Silver[a]	Gold, Platinum
SULPHURIC ACID	Titanium E-BRITE, 600	316L 200[a]	904L AL-6XN, RA333 400[a]	20Cb-3 Tantalum
PHOSPHORIC ACID (commercial)	200, 400		904L	AL-6XN 20Cb-3
NITRIC ACID	20Cb-3 904L, AL-6XN 200, 400, 600	304L	RA333[d]	E-BRITE, Zirconium Tantalum
CAUSTIC	316L Tantalum	20Cb-3	600 400	E-BRITE, 200[a]

[a] presence of oxygen or oxidizing salts may greatly increase corrosion
[b] AL-6XN useful only to 3% HCL
[c] Titanium has excellent resistance to hydrochloric acid containing oxidizers such as $FeCl_3$, HNO_3, etc. However, titanium has very poor resistance to pure, reducing HCL.
[d] Stabilize annealed 1700°F 1 hour

General Engineering Principles I

Metals and Effect of Alloying Elements:

Carbon:	hardenability, strength, hardness, and wear resistance
Nickel:	strength and toughness; minor effect on hardenability
Chromium:	strength, toughness, hardness, and wear resistance, increases depth of hardness penetration in heat treatment

General Engineering Principles I

Metals and Effect of Residuals:

Residual elements during the processing of steels can have various effects as outlined below:

Nitrogen:	strength, hardness, machinability (decreases ductility and toughness)
Oxygen:	slight increase in strength of rimmed steels (gross reduction in toughness)
Hydrogen:	(severe embrittlement of steels)

General Engineering Principles I

Nearest Foreign Equivalents of AISI Chromium-Nickel Stainless Steels

AMERICAN	BRITISH	FRENCH	GERMAN	ITALIAN	SWEDISH	RUSSIAN		
AISI	En	AFNOR	VD Eh	UNI	SIS	GOST Specification Number	GOST Designation Number	USSR Factory Designation
301		Z 12 CN 18-8	X 12 Cr Ni 17-7	X 15 CN 1707	2330 2331	—	Kh17N8	—
302	58A	Z 12 CN 18-10	X 12 Cr Ni 18-8	X 15 CN 1808	2330 2331	— — 5632-51[a]	1Kh17N9 Kh18N9 1Kh18N9	— EYa-1 Ya-1
302B						4542-54[b] —	— OKh18N9S2	EI543 EI647
303	58M		X 12 Cr Ni 18-8					
304	58E	Z 6 CN 18-10	X 5 Cr Ni 18-9	X 8 CN 1910	2332	5632-51[a] 5632-51[a] 4176-53[b]	OKh18N9 OKh18N9 OKh18N11	EYa-0 Ya-0 —
304L		Z 3 CN 18-10		X 3 CN 1911		—	Kh18N8	—
309	5S	Z 15 CNS 25-13	X 15 Cr Ni Si 20-12	X 20 CN 2412		5632-51[a] 5632-51[a]	Kh23N13 Kh25N15	EI319 EI319
309S								
310		Z 15 CNS 25-20	X 15 Cr Ni Si 25-20	X 25 CN 2520	2361	—	Kh25N20	EI332
310S								
314			X 15 Cr Ni Si 25-20		2361			
316	58H 58J	Z 6 CND 18-12	X 5 Cr Ni Mo 18-12	X 8 CND 1712	2342	— 5216-55[b] 4270-53[c]	Kh18N9M — —	EI183 EI400 EI689
316L		Z 3 CND 18-12	X 3 Cr Ni Mo 18-13					
317	58J		X 5 Cr Ni Mo 17-13					
318*		Z 8 CNDNb 18-12	X 10 Cr Ni Mo Nb 18-12		2343	5001-55[b] —	1Kh16N13M2B 1Kh16N13M3B	EI405 EI592
321	58B 58C	Z 10 CNT 18-10	X 10 Cr Ni Ti 18-9	X 8 CNT 1810	2333 2334	5632-51[a] 5632-51[a] 5632-51[a]	Kh18N9T 1Kh18N9T 1Kh18N9T	EYa-T EYa-1T Ya-1T
330*		Z 20 NCS 36-18				— — —	Kh15N35 2Kh15N35 3Kh15N35	EI612 — —
347	58F 58G	Z 10 CNNb 18-10	X 10 Cr Ni Nb 18-9	X 8 CNNb 1811	2333 2334	5050-55[b] 5632-51[a] 5216-54[b] 5632-51[a] —	OKh18N9B Kh18N11B Kh18N11B Kh18N11B OKh18N9BS	EI506 EI398 EI402 EYa-1Nb —

General Engineering Principles I

Carbon Steels - Properties:

TABLE 3.4
AISI–SAE DESIGNATIONS FOR STEELS AND THEIR MAJOR ALLOYING ELEMENTS

10xx	Plain carbon steel	48xx	Ni–Mo
11xx	Resulfurized carbon steel	50xx	Cr
12xx	Resulfurized and rephosphorized carbon steel	51xx	Cr
13xx	Mn	52xx	Cr
31xx	Ni–Cr	61xx	Cr–V
33xx	Ni–Cr	81xx	Ni–Cr–Mo
40xx	Mo	86xx	Ni–Cr–Mo
41xx	Cr–Mo	87xx	Ni–Cr–Mo
43xx	Ni–Cr–Mo	88xx	Ni–Cr–Mo
44xx	Mo	92xx	Mn–Si–Cr
45xx	Mo	93xx	Ni–Cr–Mo
46xx	Ni–Mo	94xx	Mn–Ni–Cr–Mo
47xx	Ni–Cr–Mo	98xx	Ni–Cr–Mo

Note: The last two digits indicate the carbon content (e.g., 1020 steel has 0.20% carbon). Leaded steels are identified by the letter "L" inserted between the second and third numerals (e.g., 10L45).

TABLE 3.5
TYPICAL SELECTION OF STEELS FOR VARIOUS APPLICATIONS

PRODUCT	STEEL
Aircraft forgings, tubing, fittings	4140, 8740
Axles	1040, 4140
Ball bearings and races	52100
Bolts	1035, 4042, 4815
Camshafts	1020, 1040
Chains (transmission)	3135, 3140
Coil springs	4063
Connecting rods	1040, 3141, 4340
Crankshafts (forged)	1045, 1145, 3135, 3140
Differential gears	4023
Gears (car and truck)	4027, 4032
Landing gear	4140, 4340, 8740
Lock washers	1060
Nuts	3130
Springs (coil)	1095, 4063, 6150
Springs (leaf)	1085, 4063, 9260, 6150
Tubing	1040
Wire	1045, 1055
Wire (music)	1085

REF: Serope Kalpakjian, Manufacturing Processes for Engineering Materials, Addison Wessley, 1984, pp145.

General Engineering Principles I

Carbon Steels - Properties:

TABLE 3.8
TYPICAL MECHANICAL PROPERTIES OF SELECTED CARBON AND ALLOY STEELS IN THE HOT ROLLED, NORMALIZED AND ANNEALED CONDITION

AISI No.*	CONDITION	ULTIMATE TENSILE STRENGTH MPa	ULTIMATE TENSILE STRENGTH psi × 10^3	YIELD STRENGTH MPa	YIELD STRENGTH psi × 10^3	ELONGATION, %	REDUCTION IN AREA, %	HARDNESS, HB	IZOD IMPACT STRENGTH J	IZOD IMPACT STRENGTH ft · lb
1020	As-rolled	448	65	330	48	36	59	143	86	64
	Normalized	441	64	346	50	35	67	131	117	86
	Annealed	393	57	294	42	36	66	111	123	91
1040	As-rolled	620	90	413	60	25	50	201	48	36
	Normalized	589	85	374	54	28	54	170	65	48
	Annealed	518	75	353	51	30	57	149	44	32
1060	As-rolled	813	118	482	70	17	34	241	17	13
	Normalized	775	112	420	61	18	37	229	13	9
	Annealed	625	90	372	54	22	38	179	11	8
1080	As-rolled	965	140	586	85	12	17	293	6	5
	Normalized	1010	146	524	76	11	20	293	6	5
	Annealed	615	89	375	54	24	45	174	6	4
1118	As-rolled	521	75	316	45	32	70	149	108	80
	Normalized	477	69	319	46	33	65	143	103	76
	Annealed	450	65	284	41	34	66	131	106	78
3140	Normalized	891	129	599	87	19	57	262	53	39
	Annealed	689	100	422	61	24	50	197	46	34
4340	Normalized	1279	185	861	125	12	36	363	15	11
	Annealed	744	108	472	68	22	49	217	51	37
4820	Normalized	750	109	484	70	24	59	229	109	81
	Annealed	681	98	464	67	22	58	197	92	68
5140	Normalized	792	115	472	68	22	59	229	38	28
	Annealed	572	83	293	42	28	57	167	40	30
6150	Normalized	939	136	615	89	21	61	269	35	26
	Annealed	667	96	412	59	23	48	197	27	20
8620	Normalized	632	91	357	51	26	59	183	99	73
	Annealed	536	77	385	55	31	62	149	112	82
9255	Normalized	932	135	579	84	19	43	269	13	10
	Annealed	774	112	486	70	21	41	229	8	6

* All grades are fine-grained except for those in the 1100 series that are coarse-grained. Heat treated specimens were oil quenched unless otherwise indicated. Adapted from *ASM Metals Reference Book*, 2 ed., 1983.

REF: Serope Kalpakjian, Manufacturing Processes for Engineering Materials, Addison Wessley, 1984, pp147.

General Engineering Principles I

Properties of Selected Stainless Steels:

TABLE 13-5 Compositions and properties of selected stainless steels

Steel	% C	% Cr	% Ni	Others	Tensile Strength (psi)	Yield Strength (psi)	% Elongation	Condition
Austenitic								
201	0.15	16–18	3.5–5.5	5.5–7.5% Mn	95,000	45,000	40	Annealed
304	0.08	18–20	8.0–10.5		75,000	30,000	30	Annealed
					185,000	140,000	9	Cold worked
304L	0.03	18–20	8–12		75,000	30,000	30	Annealed
316	0.08	16–18	10–14	2–3% Mo	75,000	30,000	30	Annealed
321	0.08	17–19	9–12	Ti (5 × % C)	85,000	35,000	55	Annealed
347	0.08	17–19	9–13	Nb (10 × % C)	90,000	35,000	50	Annealed
Ferritic								
430	0.12	16–18			65,000	30,000	22	Annealed
442	0.12	18–23			75,000	40,000	20	Annealed
Martensitic								
416	0.15	12–14		0.60% Mo	180,000	140,000	18	Quenched and tempered
431	0.20	15–17	1.25–2.50		200,000	150,000	16	
440C	0.95–1.2	16–18		0.75% Mo	285,000	275,000	2	
Precipitation hardening								
17-4	0.07	16–18	3–5	0.15–0.45% Nb	190,000	170,000	10	Age hardened
17-7	0.09	16–18	6.5–7.8	0.75–1.25% Al	240,000	230,000	6	

Adapted from *ASM Metals Handbook, Vol. 3, 9th Ed.*, 1980.

REF: Donald R. Askeland, *The Science and Engineering of Materials*, PWS Publisher

General Engineering Principles I

TABLE 3.13
PROPERTIES OF SELECTED ALUMINUM ALLOYS

ALLOY (UNS)	CONDITION	ULTIMATE TENSILE STRENGTH, psi × 10^3	YIELD STRENGTH, psi × 10^3	ELONGATION IN 2 in.*, %
1100 (A91100)	O	13	5	35–45
1100	H14	18	17	9–20
2011 (A92011)	T3	55	43	15
2024 (A92024)	O	27	11	20–22
2024	T4	68	47	20–19
3003 (A93003)	O	16	6	30–40
3003	H14	22	21	8–16
5052 (A95052)	O	28	13	25–30
5052	H34	38	31	10–14
6061 (A96061)	O	18	8	25–30
6061	T6	45	40	12–17
7075 (A97075)	O	33	15	17–16
7075	T6	83	73	11

* $\frac{1}{16}$ in. thick—$\frac{1}{2}$ in. thick specimen.

REF: Serope Kalpakjian, Manufacturing Processes for Engineering Materials, Addison Wessley, 1984, pp154.

General Engineering Principles I

Aluminum:

- lightweight
- good strength and thermal conductivity
- good corrosion resistance
  - resistant to concentrated nitric acid, organic acids, and sulfuric acid
- alloying, cold working and heat treatment can reduce corrosion resistance
- tensile strength 13,000 psi with 45% elongation

General Engineering Principles I

Aluminum: (cont'd)

- 1/3 the stiffness of steel
- poor wear resistance
- fatigue strength low - 18,000 psi
- Two major groups: wrought and casting alloys

General Engineering Principles I

Brass:

- alloy of copper and zinc
- known for its workability, resistance to various corrosive elements and their attractive finishes
- strength compares with that of mild steel
- much lower modules of elasticity than mild steel
- subject to cracking
- used as a shield in low energy gamma radiation and as source holders

General Engineering Principles I

Copper:

- good thermal conductor
- good corrosion resistance for normal atmosphere and calm, non-oxidizing water
- ease of fabrication
- copper does corrode rapidly and becomes brittle due to absorbed oxygen at elevated temperatures
- better strength and ductility than aluminum and magnesium
- poor creep resistance and should only be used at temperatures below 400°F (205°C)

General Engineering Principles I

Lead:

- tensile strength of about 2500 psi
- corrosion resistance to sulfuric acid, water sewage and atmosphere
- high density, specific gravity of 11.33
- low melting point
- subject to creep, creep starts to develop around 500 psi
- used as a shield in medical and nuclear industries

General Engineering Principles I

Carbon Steels:

- Generally grouped into three categories:
- Low-carbon (<0.3% carbon)
- Medium-carbon (0.3 to 0.6% CARBON)
- High-carbon (> 0.6% carbon)

- AISI-SAE designation (4 digits):
- first two digits indicate the alloying element and their percentage, last two digits represent the amount of carbon

General Engineering Principles I

Carbon Steels: (cont.)

- Ultimate tensile strength: range from 42,000 to 282,000 psi.
- Elongation: approximations between 0-35%
- Brinell hardness: 80-490
- Stress amplitude 30 to 112,000 psi
- Modulus of elasticity 20 - 30 million psi for all steels

General Engineering Principles I

Stainless Steels:

- Highly resistant to corrosion and oxidation
- Maintains considerable strength at elevated temperatures
- Characterized by their high chromium content (>12% Cr)
- Wide range of properties

Four main categories:

- Ferritic stainless steels (400 series)
- Martensitic stainless steels (400 and 500 series)
- Austenitic stainless steels (200 and 300 series)
- Precipitation-hardening stainless steels (P-H)

General Engineering Principles I

Ferritic Stainless Steels (400 series):

- Good strength
- Excellent corrosion resistance
- Moderate formability and ductility
- Relatively inexpensive
- Poor weldabiltiy
- Small amounts of carbon and nitrogen are detrimental to corrosion resistance (intergranular corrosion)

General Engineering Principles I

Common stainless steels used in SSDs:

18-8 - This is a basic group of steels that are resistant to many types of corrosion. This group is so named for its composition of 18% chromium and 8% nickel.

304 - This is a basic 18-8 steel with 0.08% carbon (maximum). It is less susceptible to carbide precipitation when it is welded, therefore it may be used over a wider range of corrosive conditions without additional heat treatment.

General Engineering Principles I

Common stainless steels used in SSD's:

304L - It was developed to minimize the amount of carbide precipitation with a carbon content below 0.03%. The "L" refers to the type of steel, a low carbon alloy. This steel finds excellent application where welding is involved and post-annealing is impractical. It does not machine well, though its corrosion resistance is similar to type 304 steel.

General Engineering Principles I

Common stainless steels used in SSD's:

316 - This steel has the ability to be annealed and cold-worked. With the addition of molybdenum, this group is highly resistant to solutions of sulfuric acid up to 5%. These steels are less susceptible to pitting corrosion where acetic acid vapor solutions of chlorides, bromides, or iodides are common. They are affected by nitric acid more so than other chromium-nickel steels.

General Engineering Principles I

Common stainless steels used in SSD's:

316L - It is similar to Type 304L. The differences are in the amount of chromium (less), more nickel and additional elements. Molybdenum improves the corrosion resistance and the high temperature strength. Mechanical properties are lower than Type 316.

General Engineering Principles I

Common stainless steels used in SSD's:

321 - Used for weldment subject to severe corrosive conditions. Titanium or columbium is added to the low-carbon 18-8 steel immunizing it to intergranular corrosion.

General Engineering Principles I

Common stainless steels used in SSD's:

347 - Where annealing is not possible, this metal can be welded with ease. It shows very good resistance to corrosion after welding. Titanium or columbium is added to avoid intergranular corrosion.

General Engineering Principles I

Common stainless steels used in SSD's:

348 - An austenitic chromium-nickel stainless steel. A stabilized grade developed to eliminate carbide precipitation and the corresponding intergranular corrosion. Low tantalum for nuclear applications gives the material low neutron cross section properties and short retention of radiation.

General Engineering Principles I

Titanium:

- High strength to weight ration
- High melting point and good high temperature properties
- Resistant to chlorides and salt water attacks
- Above 535°C the oxide layer breaks down and elements such as carbon, oxygen, nitrogen, and hydrogen embrittle the titanium
- Therefore, during gas-tungsten arc welding, the material must be protected with an inert gas until the weld cools below 535°C

General Engineering Principles I

Tungsten:

- Highest melting point of any metal
- 2.5 times the weight of iron
- High strength at elevated temperatures
- Brittleness at low temperatures
- Poor oxidation resistance
- 95% of the tungsten produced is used as an alloy for steel

General Engineering Principles I

Table I-2.2 SECTION III, DIVISION 1—SUBSECTION NA

TABLE I-2.2
YIELD STRENGTH VALUES, S_y, FOR AUSTENITIC STEELS AND HIGH NICKEL ALLOYS

Specification	Nominal Composition	Type or Grade	Class	Product Form	Spec. Min. Yield
High Alloy Steels					
Type 304 Stainless Steels					
SA-182		F304L	...	Forg.	25.0
SA-213		TP304L	...	Smls. Tube	
SA-240		304L	...	Plate	
SA-249		TP304L	...	Wld. Tube	
SA-312		TP304L	...	Wld. & Smls. Pipe	
SA-479		304L	...	Bar	
SA-351		CF3	...	Casting	30.0
SA-351		CF3A	...	Casting	35.0
SA-182		F304 & F304H	...	Forg.	30.0
SA-213		TP304 & TP304H	...	Smls. Tube	
SA-240		304	...	Plate	
SA-249		TP304 & TP304H	...	Wld. Tube, Smls. & Wld. Pipe	
SA-312		TP304 & TP304H	...	...	
SA-336		...	F8	Forg.	
SA-351		CF8	...	...	
SA-358		304	1	Wld. Pipe	
SA-376		TP304 & TP304H	...	Smls. Pipe	
SA-430		FP304 & FP304H	...	Forg. Pipe	
SA-451		CPF8	...	Cast Pipe	
SA-452		TP304H	...	Cast Pipe	
SA-479		302	...	Bar	
SA-479		304	...	Bar	
SA-351		CF8A	...	Casting	35.0
Type 309, 310 Stainless Steels					
SA-351		CH8	...	Casting	28.0
SA-351		CK20	...	Casting	
SA-451		CPH8	...	Cast Pipe	
SA-451		CPK20	...	Cast Pipe	
SA-336		...	F25	Forg.	30.0
SA-351		CH20	...	Casting	
SA-451		CPH20	...	Cast Pipe	
SA-358		309	1	Wld. Pipe	
SA-358		310	1	Wld. Pipe	
Type 316 Stainless Steels					
SA-182		F316L	...	Forg.	25.0
SA-213		TP316L	...	Smls. Tube	
SA-240		316L	...	Plate	
SA-249		TP316L	...	Wld. Tube	
SA-312		TP316L	...	Smls. & Wld. Pipe	
SA-479		316L	...	Bar	
SA-182		F316 & F316H	...	Forg.	30.0
SA-213		TP316 & TP316H	...	Smls. Tube	
SA-240		316	...	Plate	
SA-249		TP316 & TP316H	...	Wld. Tube	
SA-312		TP316 & TP316H	...	Wld. & Smls. Pipe	
SA-336		...	F8m	Forg.	
SA-358		316	...	Wld. Tube	
SA-376		TP316 & TP316H	...	Smls. Pipe	
SA-430		FP316 & FP316H	...	Forg. Pipe	
SA-452		TP316H	...	Cast Pipe	
SA-479		316	...	Bar	

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General Engineering Principles I

TABLE I-2.2
YIELD STRENGTH VALUES, S_y, FOR AUSTENITIC STEELS AND HIGH NICKEL ALLOYS

Yield Strength, ksi (Multiply by 1000 to Obtain psi) For Metal Temperatures, F, Not to Exceed													
100	200	300	400	500	600	650	700	750	800	850	900	950	1000
													High Alloy Steels
													Type 304 Stainless Steels
25.0	21.3	19.1	17.5	16.3	15.5	15.2	14.9	14.7	14.4	14.2	13.9	13.6	13.3
30.0	25.6	22.0	19.6	18.2	17.3	17.0	16.8	16.6	16.4	16.2	16.0	15.6	15.1
35.0	29.8	25.7	22.8	21.2	20.2	19.8	...	...	...	...	...	...	...
30.0	25.0	22.5	20.7	19.4	18.2	17.9	17.7	17.3	16.8	16.5	16.2	15.9	15.6
35.0	29.8	25.7	22.8	21.2	20.2	19.8	...	...	...	...	...	...	...
													Type 309, 310 Stainless Steels
28.0	25.2	23.7	22.2	21.0	19.9	19.4	19.0	18.6	18.1	17.7	17.3	16.9	16.7
30.0	27.0	25.3	23.8	22.5	21.3	20.8	20.3	20.0	19.4	19.0	18.6	18.1	17.9
													Type 316 Stainless Steels
25.0	21.1	18.9	17.2	15.9	15.0	14.6	14.3	14.0	13.7	13.4	13.1	12.7	12.4
30.0	25.8	23.3	21.4	19.9	18.8	18.5	18.1	17.8	17.6	17.4	17.3	17.1	17.0